IPM10: Computational Process Modeling for Additive Manufacturing (OSU)

Stacey Bagg[1] and Dr. Wei Zhang[2]

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[1] NASA Marshall Space Flight Center (MSFC)

[2] The Ohio State University

CIMJSEA

NSF-I/UCRC: Center for Integrative Materials Joining Science for Energy Applications

Introduction / Review

- Industrial Relevance
  - Optimize material build parameters with reduced time and cost through modeling
- Goals of the project
  - Model microstructure evolution in a powder-bed additive manufacturing process, using thermal modeling from Applied Optimization and Simultaneous Transformation Kinetics modeling at OSU.
  - Validate model using metallography from coupons manufactured at MSFC using Cusing M2 powder-bed system and in-situ data acquisition from QM Meltpool.
- Objectives set for the first year
  - Build samples on Cusing M2 machine and record data using QM Meltpool. Share data and parameters with AO for calibration of powder-bed AM process model.
  - Conduct metallography on samples produced
  - Begin calibration and modeling of STK at OSU.
  - Project started June 2013

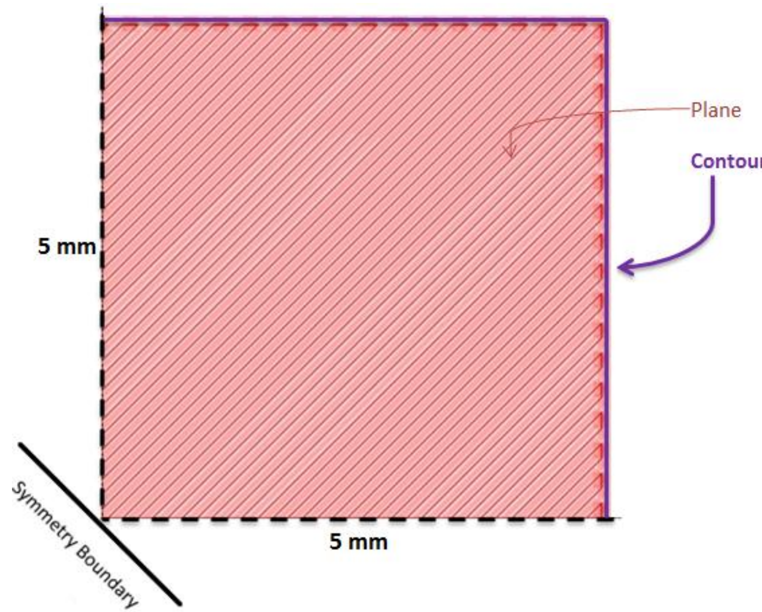
Project Milestones and Timing

Date plan Jul 2013	Date Completed	Milestone/Deliverable	Status
7/30/2013	12/17/2013	Signed Space Act Agreement (NASA MSFC) and CIMJSEA Membership Agreement	100%
9/2013	1/3/2014	Conduct single-track builds	100%
10/2013	1/10/2014	Deliver single-track QM Meltpool data to AO	100%
11/2013	10/24/2013	Define coupon sample build parameters	100%
12/2013	10/25/2013	Conduct coupon sample builds	100%
1/2014	1/10/2014	Deliver coupon sample QM Meltpool data to AO	100%
3/2014		Conduct metallography on coupon samples	10%
5/2014		Calibrate STK models	0%
7/2014		Report initial results from AO modeling	0%
7/2014		Report initial results from STK models	0%

QM Meltpool Data

- QM Meltpool is Concept Laser GmbH in-situ quality management module
  - A high-speed IR Camera measures the integrated intensity of the IR radiation and captures images. Software determines from camera images how many pixels are within a threshold color level corresponding to molten material.
  - A Photodiode measures the brightness intensity of the melt pool.

Part	Layer	Contour	Diode Intensity	From Photodiode, average intensity value of contour trace
			Meltpool Intensity	From Camera, average integrated IR intensity of contour trace
			Meltpool Area	From Camera, average number of pixels above threshold color level during contour trace
		Plane	Diode Intensity	From Photodiode, average intensity value of bulk material / hatch scan
			Meltpool Intensity	From Camera, average integrated IR intensity of bulk material / hatch scan
			Meltpool Area	From Camera, average number of pixels above threshold color level during hatch scan



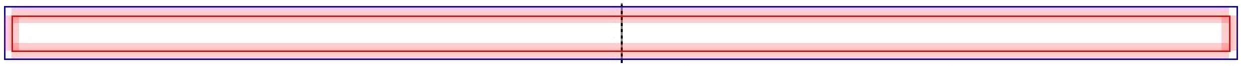
Powder Bed AM Experiments

Build geometry	Characterization	Parameters (EOS @EWI)	Parameters (M2 @MFSC)	Heat treatment
Analysis of as-received powders	SEM and chemistry analysis (e.g., EPMA)	N/A	N/A	N/A
Single track – straight lines	Optical microscope to reveal the fusion zone size and shape for modeling	Power, speed and hatch spacing?	Power, speed and hatch spacing?	N/A
Single track – hollow squares	Optical microscope to reveal the fusion zone size and shape for modeling			N/A
Cubes (15 and/or 20 mm^3)	Optical, SEM (and EBSD), TEM, EDS and micro-hardness			TBD
Cubes with 45^o support to study orientation effect	Optical, SEM (and EBSD), TEM, EDS and micro-hardness			TBD

Initial Considerations

Single Track Builds

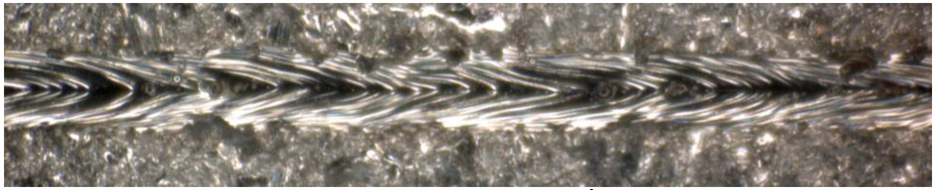
- Ultimately 3 cases of “single tracks”
  1.) Track on SS build plate with no powder
  2.) Track on SS build plate with 1, 2, 3 layers of powder
  3.) Track on In718 build with 1 – 10 layers of powder
- For single track, a continuous laser path is desired; Machine control only allows this for part contours (e.g. geometry perimeters)
  - “Single Track” geometry is therefore defined as a rectangle perimeter
- All samples have been built using In718 powder in the Concept Laser M2, and QM Meltpool data were compiled and provided to Applied Optimization, OSU and EWI, and are available to other CIMJSEA members upon request



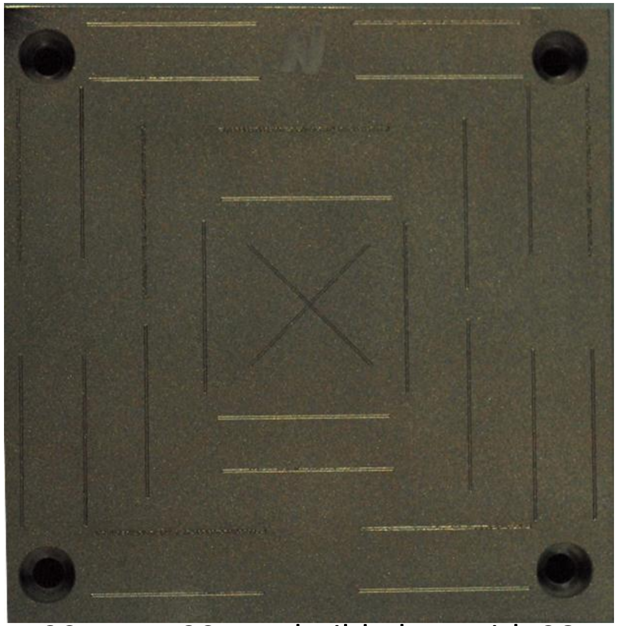
Red line is laser path, blue line is CAD OML geometry definition and red shade is presumed final track geometry

1.) Track on SS build plate with no powder

- 2 cases considered
  - 28 lines using the same power and speed (record variability in process)
  - 8 sets of parameters (power and speed); 3 tracks each for statistical significance



Power 126 W Speed 600 mm/s - Magnified



90 mm x 90 mm build plate with 28 "single tracks"

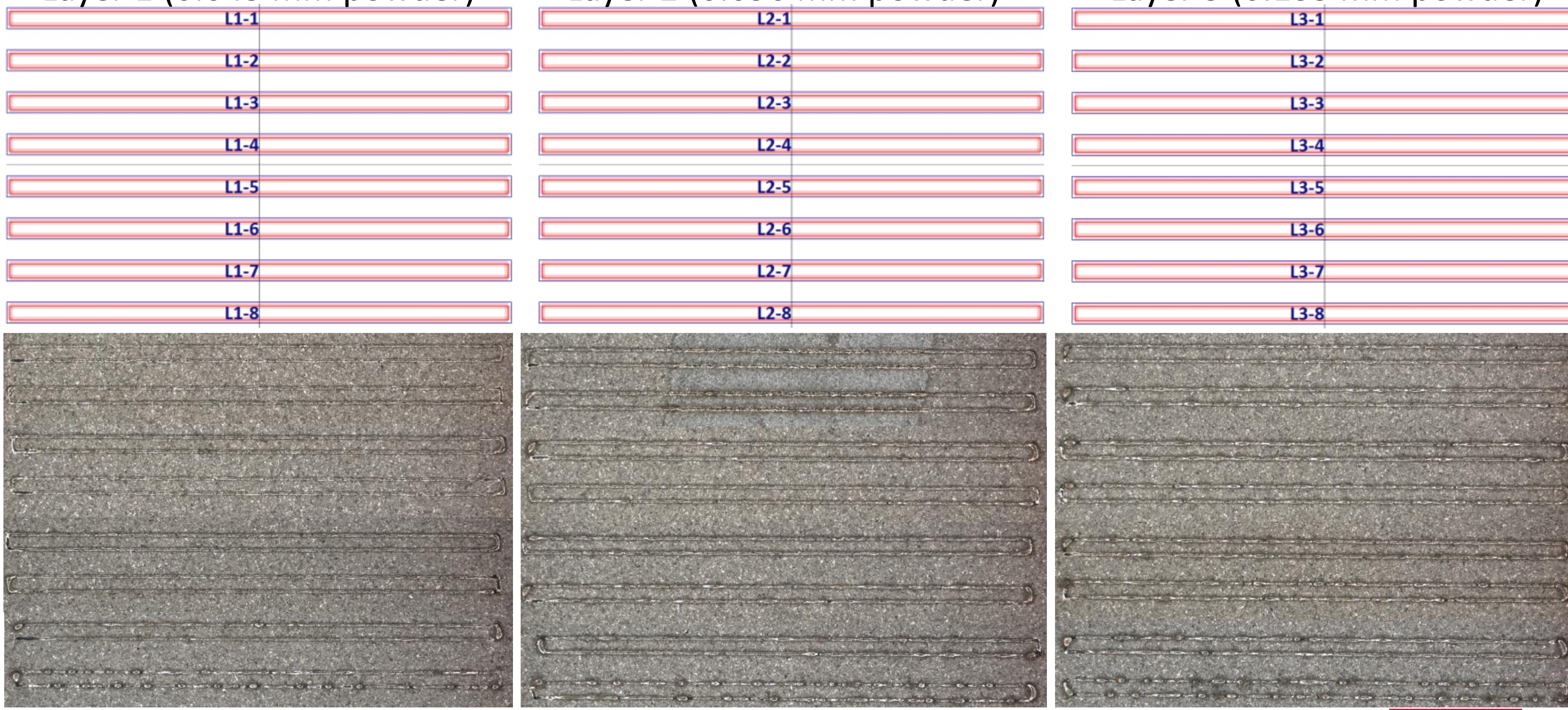
Power 126 W Speed 600 mm/s

Power 321 W Speed 850 mm/s

2.) Track on SS build plate with 1, 2, 3 layers of powder

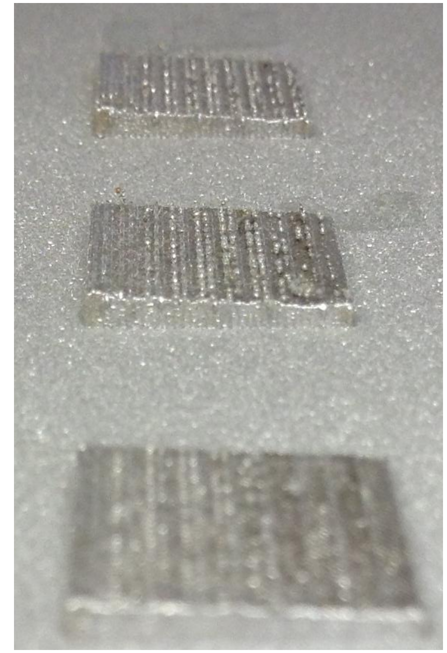
- 8 sets of parameters (power, speed) over 3 layers of In718 powder

Layer 1 (0.045 mm powder) | Layer 2 (0.090 mm powder) | Layer 3 (0.135 mm powder)

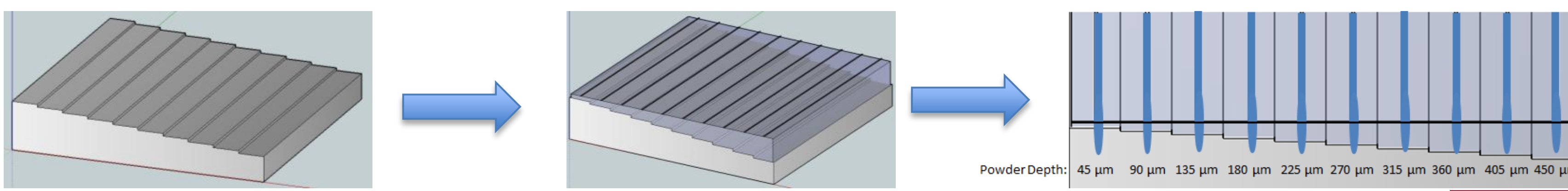


3.) Track on In718 build with 1 – 10 layers of powder

- Scanning on previously deposited material rather than SS build plate is a more realistic situation
- Printed single tracks on previously printed stepped base geometry
  - Same parameters for base and its single tracks
  - 8 sets of parameters (speed, power)
  - 10 mm x 10 mm x 1 mm base
  - Steps are 1 layer thick x 1mm wide
  - One layer of powder on “top” step, and subsequent steps will have 2, 3, 4… layers

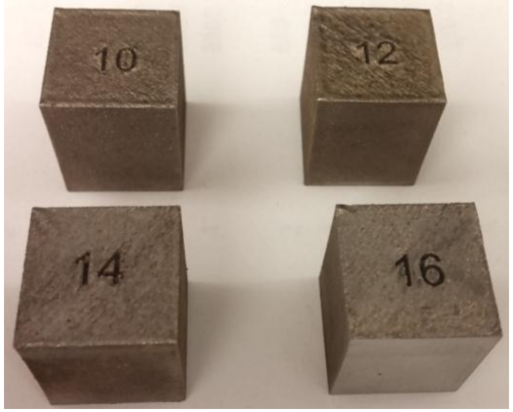


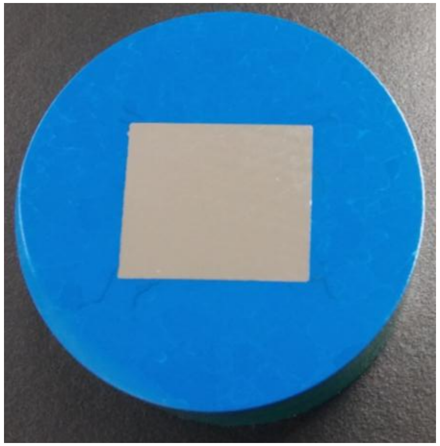
As-built single tracks on In718 bases



Coupon Builds

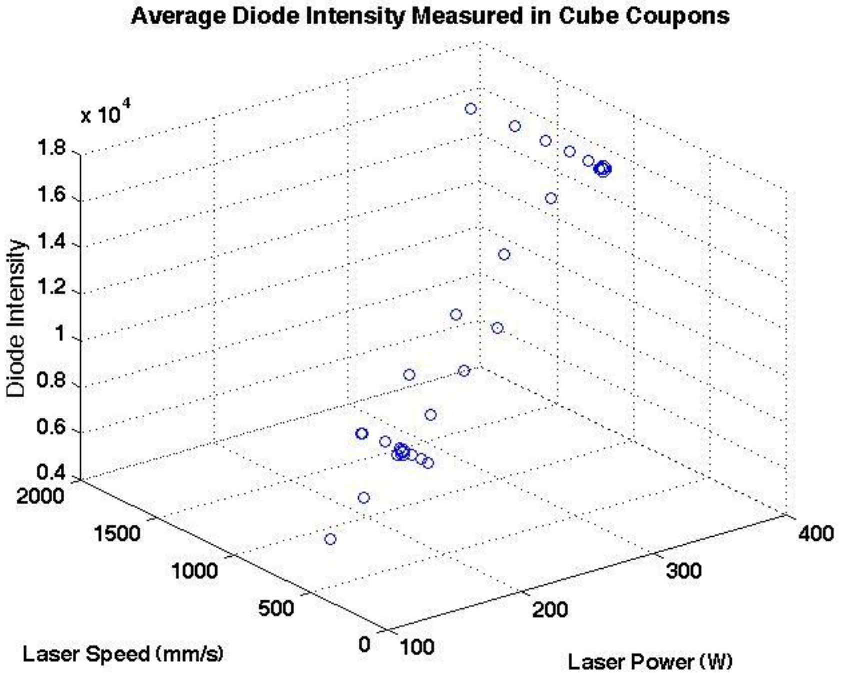
- Printed 15 mm x 15 mm x 15 mm cubes at 36 different parameter sets using In718 powder in the Concept Laser M2 machine
- QM Meltpool data for all 36 samples were compiled and provided to Applied Optimization, OSU and EWI, and are available to other CIMJSEA members upon request
- Samples representing 8 parameter sets corresponding to single tracks have been mounted and polished; metallography forthcoming

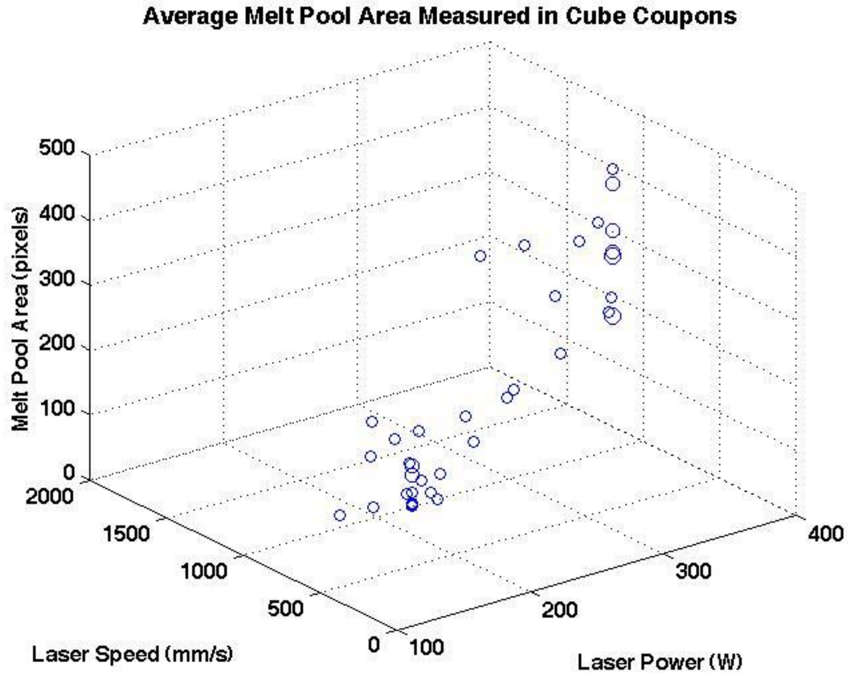




QM Meltpool Data

- Diode Intensity highly linear with Power
- Melt Pool Area highly proportional to Melt Pool Intensity





Next Steps

- Examine weld bead geometry and provide data to AO
  - Image and record shape and geometry of weld "scallops"
- Examine microstructure to understand microstructural evolution to as-built condition
  - Record grain shape, size, orientation, EBSD
  - Compare bottom and top layers
- Measure and record micro-hardness over the height of the samples (build direction)
- Evaluate samples for porosity, cracking (inter-dendritic, liquation), dendrite arm spacing, TEM, Microprobe, etc. as determined by team after initial results reported
- Begin calibration and modeling of STK at OSU

Questions?